EFFECTIVENESS OF ILIZAROV RING FIXATOR IN THE TREATMENT OF INFECTED NON UNION OF TIBIAL FRACTURES IN ADULTS.

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CERTIFICATE

This is to certify that this dissertation entitled "**EFFECTIVENESS OF ILIZAROV RING FIXATOR IN THE TREATMENT OF INFECTED NONUNION OF TIBIAL FRACTURES IN ADULTS**" is the bonafide original work of **Dr.T.ARAVINDH** in partial fulfillment of the requirements for M.S.Orthopaedics Examination of the Tamilnadu Dr. M.G.R. Medical University to be held in APRIL - 2013. The period of study from 2010 to 2013.

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DECLARATION

I, Dr.T.ARAVINDH , solemnly declare that the dissertation title "**EFFECTIVENESS OF ILIZAROV RING FIXATOR IN THE TREATMENT OF INFECTED NONUNION OF TIBIAL FRACTURES IN ADULTS"** is a bonafide work done by me at Thanjavur Medical College, Thanjavur during 2010-2013 under the guidance and supervision of **Prof. Dr. DR.A. BHARATHY**, Thanjavur Medical College, Thanjavur. This dissertation is submitted to Tamilnadu Dr. M.G.R Medical University towards partial fulfillment of requirement for the award of **M.S. degree in Orthopaedics.**

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INTRODUCTION

Infected non-union of bones is a challenging problem to any orthopaedic surgeon. Since by definition, non unions can only be diagnosed retrospectively when at least six months have elapsed since the fracture and when there is evidence that union will not take place, infection under these conditions tend to become chronic often with multi-drug resistant organisms. Infected nonunion brings together the problems of resistant bone infection and loss of stability of bone.

Introduced by Prof.Gavril Abramovich Ilizarov has changed the face of treatment of open fractures, bone defect, non-union and deformities. From 1990, till date, for the past 20 years, Ilizarov's method has been gradually replacing other modalities of treatment for infected muscular skeletal conditions. Osteoporotic fracture fragments with infected bone defects and poor soft tissue condition, remain a challenge for orthopedic surgeons. Internal fixation with a flap, massive autografting with a flap are other options .In presence of infections, such treatment with internal fixation modalities give poor results due to formation of biocalyx on the implant site.

In case of tumor resections with bone loss, allograft (or) custom mega prosthesis are done in developed countries .In developing countries with a huge population ,the treatment cost is around 2 lakhs.This decides the problems of mechanical problems of prosthesis and allograft rejection .In such conditions regenerating the patient bone to fill the defect is a better option.

Non-unions of bone tend to occur 1. 2% to 10% of fractures.Non-union are traditionally treated with freshening of bone ends which results in some shortening and fixation which need in some amount of soft tissue dissection, bone grafting which associated with some sorts of morbidity.

In acute fractures of long bones, the routine method of treatment, rod type Ex-Fix done after debridement on day 1, followed by split thickness skin graft on any raw area waiting for union in plaster (or) fixation, followed by bone grafting of the fracture .In the above method of treatment, Patient usually admitted for more than a month initially and sent home reviewed as op cases followed by bone grafting procedures and another period of 2(or) more months. The entire period of 9 to 15 months, a patient is rendered non-weight bearing.

Vehicular accidents usually involves young adult male individuals, who are usually bread winner of the family .If they are put to protracted treatment period as mentioned above ,it would put more mental strain on the patient and the family.

In such a condition, if an acute fracture is fixed with Ilizarov fixation and mobilized immediately, it would be a boon to such a suffering patient. However in an infected non-union the classical modalities of treatment ranges from prolonged immobilization, aggressive surgical debridement followed by extensive reconstruction using bone graft and micro vascular tissue transfer technique to electrical stimulation. These techniques had variable rates of success and included multiple extensive procedures with great blood loss, prolonged hospital stay, limited ability to correct limb length discrepancy and lack or early functional rehabilitation.

Prof. Gavril Abramovich Ilizarov

Professor Gavril Abramovich Ilizarov from the Siberian town of Kurgan in Russia, in 1950, developed a circular external skeletal fixator which employed the principle of distraction osteogenesis to attain union, correct deformities and eradicate infection in infected non-union. This modality of treatment has become the ultimate solution for infected non-unions since it was introduced worldwide.

AIMS AND OBJECTIVES

The aim of this work is to study and analyze the effectiveness of Ilizarov ring fixator in the treatment of infected non union in adult tibial fractures.

The aim of treatment of infected non-union is to achieve a stable union without residual infection, deformity or shortening.

The various techniques that have been used previously for this condition including surgical debridement, bone grafting, electrical stimulation etc. have all produced inconsistent results.

The principle of Ilizarov method along with the technique of bone transport allows the orthopaedic surgeon unprecedented control over osteogenesis, radical debridement of infected bone and soft tissue while maintaining stability, improves the vascularity of local tissues, simultaneous correction of deformity and limb length discrepancy while allowing early post operative mobilization and rehabilitation.

REVIEW OF LITERATURE

A diagnosis of non-union is justified only when there is evidence either clinical or radiological, that all attempts of healing have ceased and union is highly improbable.

In 1986, for the purpose of testing bone healing devices, an FDA panel defined non-union as established when a minimum of nine months has elapsed since injury and the fracture showed no visible progressive signs of healing for three months (6).

The above criteria cannot be uniformly applied and varies according to the bone and site (6). Although definitions remain arbitrary, the AO standard of failure to unite after 8 months is probably the most widely accepted criteria for non-union (21).

AETIOLOGY OF NON-UNION

The exact causes of the generation of a non union of any bone are still unknown. However the factors that predispose to non-union are

1. Factors related to injury
   a. High energy trauma
   b. Open injury
   c. Comminuted fracture or segmental loss
   d. Impairment of vascularity
2. Treatment related factors
   a. Insecure fixation

b. Excessive stripping during open reduction reduces vascularity of the fracture ends.
c. Insufficient period of immobilization
d. Distraction of bone ends by rigid fixation.
e. Inadequate and late debridement with resultant infection
f. Radical debridement with large bone defect.

These factors in isolation or in combination may cause failure of union (24).

CLASSIFICATION

The classification of non union of long bones has traditionally considered vascular status and biological activity of the bone ends. In 1960 Judet & Judet and later Muller, Weber and Cech and others differentiated two chief types of non-unions.

1. **Hyper vascular or Hypertrophic non-Union**

The bone ends are viable and capable of biologic reaction.

a. "Elephant foot" type non-union

These are hypertrophic and rich in callus. They result from insecure fixation or premature weight bearing in a reduced fracture.

b. "Horse hoof" type non-union

These are mildly hypertrophic and poor in callus. They occur after a moderately unstable fixation with plate and screw. The ends show some callus insufficient for union and sometimes a little sclerosis.

c. **"Oligotrophic" type non-unions**

These are not hypertrophic and callus is absent. They typically occur after major displacement of a fracture, distraction of the fragments or internal fixation without accurate apposition of the fragments.

2. Avascular non-union or atrophic type non-union

The ends of the bone are atrophic or avascular and are incapable of biologic reaction.

a. **Torsion wedge non-unions:** These are characterized by the presence of an intermediate fragment in which the blood supply is decreased or absent. It unites to one main fragment but not to the other. These typically are seen in tibial fractures treated by plate and screws.

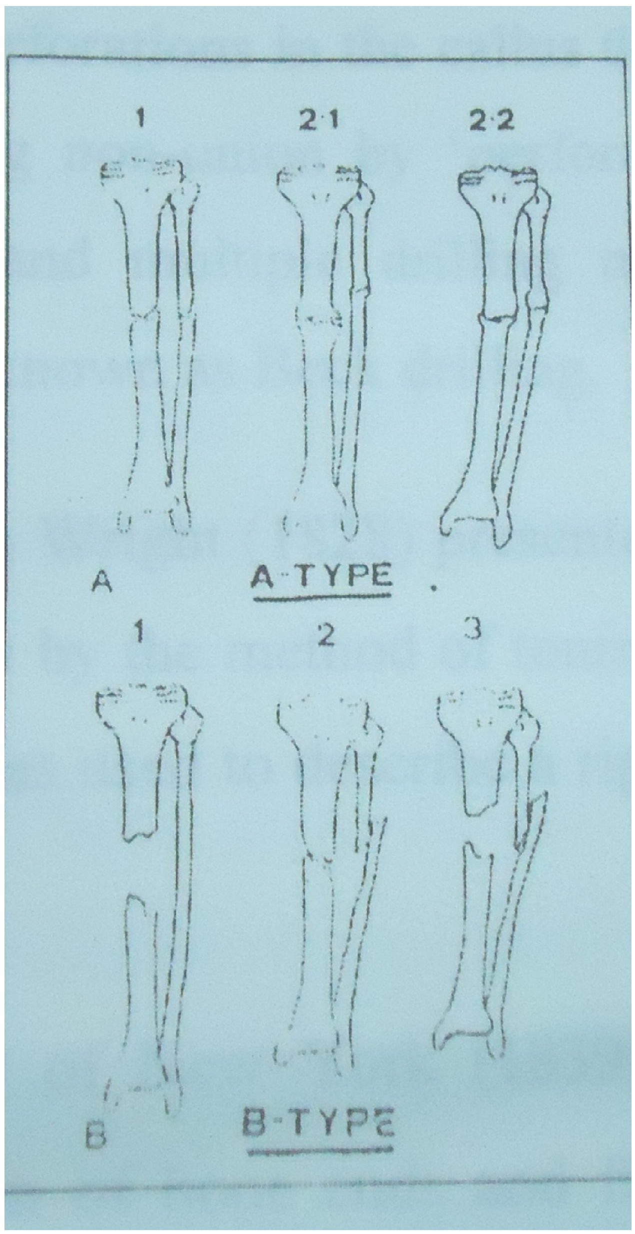
b. **Comminuted non-unions:** These are characterized by the presence of one or more intermediate fragments that are necrotic. The roentgenogram shows absence of any sign of Callus formation. Typically these non-unions result in the breakage of any plate used in stabilizing the acute fracture.

c. **Defect nonunion:** These are characterized by loss of a fragment of diaphysis of a bone. The ends of the fragments are viable but union across the defect is impossible. Later the ends of the fragments become atrophic. These non-unions occur after open fractures, loss of bone fragments during injury or dressing or during debridement and sequestration in osteomyelitis.

d. **Atrophic non-unions:** They result when intermediate fragments are missing and scar tissue that lacks osteogenic potential is left in their place. The ends of the fragments have become osteoporotic and atrophic.

DROR PALEY CLASSIFICATION:

Dror paley had classified non union. This system made decision making as simple while treating infected fractures. There are two types A and B; which further divided into different subtypes.



The history of the treatment of non-union:

Prior to the 1900 there were very few works regarding the treatment of non-union and most books had only brief chapters devoted to non unions.

Alexis Boyer (1805) delivered a series of lecturers which had a section devoted to non unions. He used phrases “failure of consolidation” or ‘lack of generation of callus’ to describe non-unions. He also suggested prolonged immobilization with frequent rubbing of fracture ends and surgery involving resection of bone ends and immobilization of the parts. Dr. Philip Physik of Philadelphia (1802) reported successfully treating a case of non-union of the humerus by the introduction of a ‘seton’ with the idea of exciting suppuration and granulation which would subsequently ossify.

Gibson’s test (1927) recorded the method of John Hunter, Sir Charles Bell and Samuel Cooper who had all treated non-union by resection of bone ends. Dr. Joseph White (1818) treated a case of non-union of the tibia by making several perforations in the callus thus anticipating by many years the method of treating non-union by ‘perforation of the callus’ described by Brainard (1854) and multiple drilling method recommended by Wildey (1914) later to be known as Beck drilling.

Dr. Thomas Wright (1828) presented the results of treatment of three cases of non-union by the method of tourniquet as advised by Dbrodie, accelerated fracture healing due to venous tourniquet. The word tourniquet was used to describe a rigid external fixation –all three cases healed.

John Heard of New York (1839) reported a series of non-unions treated by resection of bone ends and fixation of the ends by silver wire. This was the first case of internal fixation in the USA.

Edward Harts Horne (1841) published his thesis on non-unions of fracture. He was one of the first to use the term pseudarthrosis. Seerig was believed to have been the first. The monograph described a wide variety of non surgical methods including irritative application, infections into the fracture site, electrical stimulation, friction of bone ends against each other and local pressure applied by a splint.

Henry H Smith of Philadelphia (1855) described a method based on the rationale of "pressure and motion at the seat of the fracture". It involved the use of an apparatus which was the forerunner of the modern functional brace.

Henry J Bigelow (1867) after reading the work of Ollier was convinced regarding the importance of the periosteum in fracture healing.

Nicholas Senn (1899) Chicago reported the use of bone grafting by Nussbaum in Germany and Mc Ewan in Scotland. Massive cortical grafts were used by Albee in 1915 in his C.O.R.R. Chutro (1918) described the technique of cancellous strip grafting.

Phemister (1931) advocated full thickness cortical graft along with its endosteal surface. Gallie (1931), Mowlen (1944), Higgs (1945), Abbott Scholtstaedt, Saunders Bost (1947) established beyond doubt the superiority of cancellous bone grafting. Forbes (1961) raised osteoperiosteal flap before strip grafting.

The use of bone grafts in non-union after radical debridement became more possible after the advent of antibiotics in the second half of the century. Mowlew (1944, 1945) was the first to use grafts in infected cavities.

Rhinelander (1970) described the technique of open cancellous bone grafting which was later popularized by Papineau. In this technique skin coverage is delayed until after graft placement and coverage by granulation tissue.

The advances in internal fixation like Dynamic Compression Plating and interlocking nails have improved success rates in non unions not associated with infection.

Advances in the recent years in the field of microsurgery allows reconstruction of large bone defects with vascularised bone grafts these are more efficient. However in the lower limb the difference in size between the host of transplanted bone produces stress concentration resulting in prolonged recovery time.

The advent of the Ilizarov technique in 1950 has given the surgeon the versatility to attain union, correct deformities, correct limb length discrepancies and allow early functional mobilization of the patient.

EVOLUTION OF TRANSOSSEUS OSTEOYNTHESIS:

It was during and after the second world War, there had been greater use of external fixator for the management of open fractures.

Amesbury of USA (1831), Malagaigne of France and Engelhard from Latvia (1857) were among the first surgeons to use external transosseous equipment

In 1948 Sir John Charnley published by description called "Compression osteosynthesis" based on his observation in 67 patients for treating infected knee condition, by his compression device finally achieving knee arthrodesis in all cases.

In 1948, Greifensteiner invented a form of external fixation and published his observation on 100 patients in treating infected pseudarthrosis following gunshot wounds. Subsequently this method was modified by many workers like Vastmann, Herzen, King and others.

In 1902, Lambotte of Belgium developed a bilateral fixator consisting of four threaded half-pins held between two metal plates.

In 1926 Rozen from USSR developed a device called osteostat, a type of external fixation.

In 1930, Stader developed an external fixator and applied to 27 patients with infected tibial factures. This actually followed a pilot study on treating fractures in canines. There were some limitations for this apparatus .This led to the development of new external fixator including those of Hoffman, Haynes, Anderson and Watson-Jones.

Finally researches led to the development of external fixators with the use of tensioned wires. Dickson and Diveley's apparatus' was one of the first devices of this type.

In 1938, Bosworth designed a lengthening apparatus. Anderson in 1936, Ettinger in the same year developed their own external transosseous equipment. During 1956 and 1957 it was by Florenzky and Radin, developed external transosseous equipment in Soviet Russia.

In 1939, Haynes described a fixator with arches, tensioned wires and threaded rods. The best device in this group; however appear to be Gudushauri's fixator for treating open fractures, pseudarthrosis, non-unions.

However all these instruments lack the ability to find a solution to all these problems. It was by G.A.Ilizarov by his innovation solved all these problems by making his instrument more versatile.

Treatment of non-union

The principles of treatment of non-union are

1. Correction of biomechanical factors leading to non-union
2. Adequate apposition of bone ends.
3. Ensuring stability at the site.
4. Promote osteogenesis

The factors to be considered before initiation of treatment are

1. Type of non-union and status of bone: This depends on the type of fracture and the duration and method of treatment initially employed.
2. Condition of soft tissue: Adequate soft tissue cover is important for the success of treatment
3. Presence of infection: Control of infection is essential before any definitive procedures to correct non-union.

The requirement common to all successful techniques are good reduction, sufficient bone grafting and firm stabilization of the fragment.

Reducing fragments

When the fragments are in good position but are separated by fibrous tissue, extensive dissection is usually undesirable. Leaving periosteum, Callus and fibrous tissue intact about the major fragments, preserves their vascularity and stability, and after a bridging graft or grafts have united with the fragments the intervening fibrous tissue and callous ossify.

Plating and bone grafting of displaced non-union of most long bones require an extensive exposure. This produces the scar tissue about the non-union to be excised so that grafts can be kept over the relatively normal bone.

The fragments are mobilized preserving their normal soft tissue attachments as much possible then rounded ends are resected so that contact will be maximum. Medullary canals are cleared of fibrous tissue to aid in medullary osteogenesis and they are then apposed as closely as possible.

Bone grafting

For many years, the most frequently used method of treatment of non-union has been bone grafting and numerous techniques have been described.

Autogenous grafts are obtained from primarily three bones the ilium, the tibia and the fibula. The ilium and proximal tibia provide cancellous bone, and the tibia and fibula, cortical bone. Free vascular bone grafts have been tried successfully for bridging large defects in bones. Fresh or refrigerated allogenic bone for grafting may be used when the source of fresh autogenous bone not available. However, obviously the osteogenic properties of allogenic bone are inferior to those of fresh autogenous bone.

Various techniques of bone grafting include onlay bone grafting with or without internal fixation. Dual onlay grafting, cancellous insert grafts, massive sliding grafts and whole fibular transplants.

Internal fixation

Internal fixation in the treatment of non-unions should provide sufficient stability for fracture healing without excessive rigidity. The choice of internal fixation depends on the type of non-union, the condition of the soft tissue and bone fragments and the size of the bony defect. Plate and screw fixation with or without bone grafting usually is adequate for hypertrophic non-unions if the bone is not osteoporotic and the fragments are large enough for firm screw fixation.

Medullary nailing, especially interlocking nailing is useful in non-union of long bone such as tibia, femur and humerus. If the alignment is acceptable or closed reduction can be obtained, closed technique can be used. When open technique is used, only limited exposure and dissection are required. Bone grafting usually is not required. Early weight bearing is possible. The primary contraindication for medullary nailing is current or prior infection. However, medullary nailing frequently is successful as a salvage operation for infected non-unions.

External fixation

External fixation may be used for temporary or definitive stabilization. One advantage of external fixation is that it is relatively non-invasive and does not disturb the soft tissue surrounding the non-union. Other advantages are the ability to correct deformity and provide stable fixation.

Electrical stimulation

About three electrical and electromagnetic methods are available for the treatment of non-unions. These methods are either invasive requiring the implantation of electrodes, semi-invasive requiring the percutaneous application of multiple electrodes or non-invasive by capacitive or inductive coupling. Several devices using inductive coupling differ in their configuration, some trying to recreate the Helmholtz configuration and others using a U-shaped coil. An array of electrical or electromagnetic wave forms has proven beneficial from direct current application to square wave generations to unusual wave forms.[10]

Bone Morphogenetic Protein

Johnson, Urist and Finerman discovered bone morphogenetic proteins which have a bone induction capacity. Although the results with human BMP are somewhat coincidental with advanced techniques of stabilization, they are still impressive, especially in difficult distal tibial non-unions and large femoral defects. Studies have shown that composite grafting is consistently superior to BMP, marrow or diaphyseal grafts alone suggesting a mesenchymal target cell in the marrow that is probably more responsive than perivascular mesenchymal cells. [25]

The principles of Ilizarov as applicable in the treatment of Non-union

In the past, surgeons performing limb lengthening have observed spontaneous new bone formation in the widening distraction gap. Professor G.A Ilizarov since 1951 was engaged in clinical, biological, engineering and basic science research that has led to the discovery of the 'law of tension stress' gradual traction on living tissue creates stresses that can stimulate and maintain the regeneration and active growth of certain structures. The bony generation is characterized by the stimulation of both proliferative and biosynthetic cellular functions and depends upon adequate blood supply and stimulus of weight bearing.

BIOMECHANICS OF COMPRESSION AND DISTRACTION FORCES AND THEIR EFFECT ON OSTEOGENESIS:

There were many theories regarding bone formation by the mechanical influences chiefly the compressive and distractive forces. In 1862,Gurlt by studying fracture healing stated that mutual compression of fragments stimulates osteosynthesis.

Wolff based on his experiments formulated his "Law of bone transformation" by studying the effect of both compressive and distractive forces on new bone formation. In 1882 Roux stated that constant pressure "gives birth to bone tissue" while distraction softens. They postulated both compressive and distractive forces promote bone formation. Both of them observed prominent callus on the concave i.e. on the compression side.

These observations were challenged by many researchers and authors. Jansen based on his studies in fracture neck of femur, knee ankylosis and thoracic kyphosis concluded that distraction retards bone formation. Krompecher concurred that traction produce inferior callus. Kagan on studying femoral fractures treated by traction stated that traction alters the healing potential of bone having suppressing effect on fracture healing and poor callus formation.

Many authors considered the presence of even a small gap by distracting forces lead to pseudarthrosis.

In 1925 Wehner noted marked callus on the concave side. Lexer explained this phenomenon as a response of dense vascular network on the concave side rather than on the distraction side.

Pauwels on studying femoral neck fractures found that more horizontal the fracture line more favorable are the conditions for bone healing due to the effect of compressive forces. Based on his observation he suggested subtrochanteric osteotomy for treating nonunions. Alekseenkof showed in histologic studies callus formation was rapid in compression side rather than distractive side.

Kushner supported Wolff's law that distractive forces stimulate bone formation. In 1862 in their Huter and Volkmann formulated their theory that excessive compression leads to bone atrophy and retarded growth whereas decreased compression and moderate distraction enhances osteogenesis and promote bone growth.

Thus there was great contrary over quality and quantity of bone formation by the mechanical influences .Ilizarov and his workers explained this contrary by the differences in the methods these authors applied to treat the bony condition. Based on their clinical and observational studies and also by reviewing literatures they explained a new theory on bone formation by the compressive and distractive forces. He coined the term "TENSION STRESS" effect.

In the presence of rigid and stable fixation both compressive and distractive forces promote new bone formation by the marrow, periosteum and endosteum. It is that the distractive forces stimulate bone formation from the connective tissue.

The osteogenic activity of connective tissue is stimulated by tension stress effect when the tissue is stabilized. The quality of new bone depends on the distractive force and the area of cross section and the rate and rhythm of distraction.

In conjunction with osteotomy without damaging periosteum, nutrient vessels and marrow there is more rapid bone growth. He termed this procedure as corticotomy.

Compression can either enhance or retard new bone formation depending on many factors like compressive load, blood supply and quality of fixation. The effect of compression should be studied in combination of other factors not as an isolated phenomenon.

The Biology of Distraction

Mechanical forces can produce two separate biological processes.

1. Distraction osteogenesis

It is de novo production of new bone by induction between bony surfaces that are gradually pulled apart. The biological bridge between the bony surfaces arises from local neo-vascularisation and spans the entire cross section of the cut surfaces. During distraction, a fibrovascular interface is aligned parallel to the direction of distraction while new bone columns length to the gap. When biological and mechanical conditions during distraction are ideal, bone is formed by pure intramembraneous ossification.

2. Transformation osteogenesis

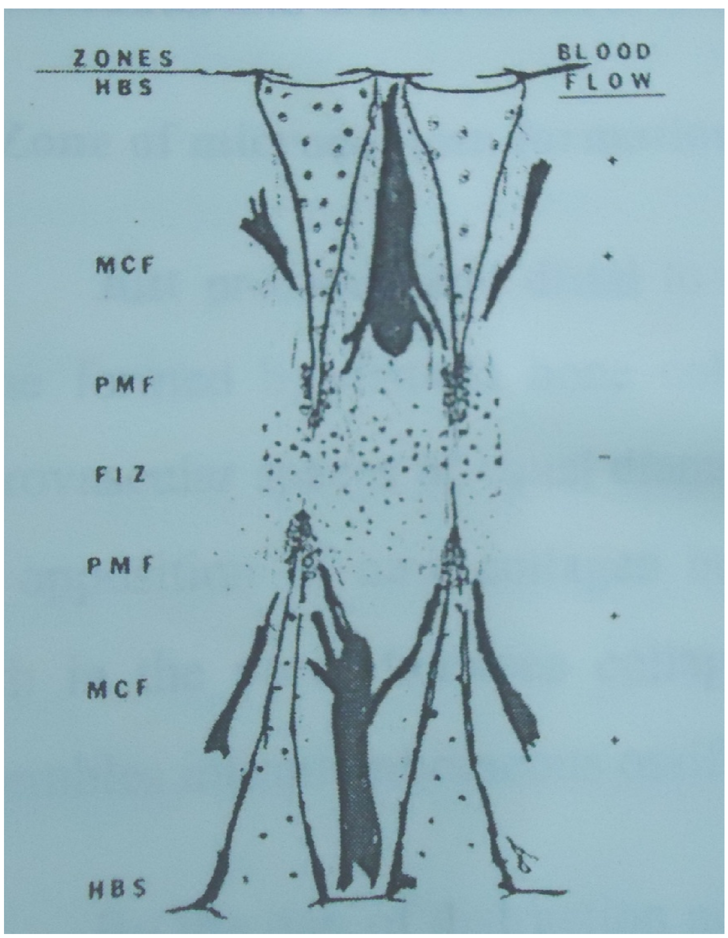
It is the mechanical stimulation of a pathological bony interface to regenerate normal bone continuity. Depending on the stability and composition of pathological interface, variation in compression and distraction induce osteogenesis. A stiff fibrous nonunion is treated initially by distraction to induce new bone by distraction osteogenesis followed by compression to transform the osteogenic bridge into solid bone. (Accordion technique)

Histology of distraction osteogenesis

When a distraction force is applied between a bony interface, the force is unequally distributed throughout the tissue between the sectioned fragments. The distraction force is always stronger at the borders, which is called as advance front, gradually grows weaker and weaker towards the centre. At the centre of the tissue where the forces opposing each other the two forces tend to cancel each other and a central quiet zone is formed. It is in this zone of neutral forces that the first sign of osteogenesis is initiated. This osteogenesis continues as long as the distractive forces are acting on the system. Under ideal conditions this will resemble a special growth plate created within the elongated bone. As soon as the distraction ceases the osteogenic area invades the entire tissue rapidly.

Five distraction zones have been defined within the site of distraction osteogenesis by quantitative computer tomography.

Model of distraction osteogenesis



HBS – Host Bone Surface

MCF – Micro Column Formation

PMF – Primary Mineralization Front

FIZ – Central Fibrous Interzone.

1. Central Fibrous Interzone (FIZ)

This is central radiolucent zone persisting throughout the distraction. This zone is formed by parallel bundles of vascular dense fibrous tissue resembling tendon.

2. Primary Mineralization Front (PMF)

Immediately adjacent to the radiolucent zone is a transitional zone known as primary mineralization front. This zone is formed by large vascular spaces with immature endothelial cells suggestive of capillary budding. This zone also contains spindle cells oriented longitudinally with matrix showing early calcification. The histology at the region resembles that of Sharpey's fibers. This is the zone of vascularisation and early calcification and is seen on both sides of the central fibrous interzone.

3. Zone of Micro Column Formation (MCF)

Just proximal and distal to the transitional zone, this is the baseline zone formed by distinct bone columns of uniform diameter separated by fibrovascular spaces of equal diameter. This column slowly increases in size by opposition of new collagen bundles. Mineralization occurs intimately within the pores between collagen bundles. Histology of this sequence resembles intramembraneous ossification.

By the day10 of distraction new bone is first seen forming at two ends arising from the entire cross section including spongiosa, cortex and periosteum.

At day 21 of distraction, the new bone had differentiated into microcolumns with a maximum diameter of 200 microns. The central region of the osteogenic area remains as fibrous interzone containing trace amounts of calcium and no crystallized hydroxyapatite.

The fibrous interzone persists throughout the distraction averaging 3 or 4 millimeters in length. It follows an undulating course parallel to the margins of the bone ends.

Following distraction the bone columns bridge across the fibrous interzone and by post operative day 77 the osteogenic area has remodeled radiographically demonstrating early cortex formation. By post operative day 119 the osteogenic area contains lamellar bone with Haversian system and haematopoietic marrow. The histology is indistinguishable from host bone with normal cortex, trabecular bone and bone marrow elements. The linear rate of this osteogenesis is calculated as over 200 microns per day.The newly formed tissue is called “**Regenerate”.**

EFFECT OF DISTRACTION ON SOFT TISSUES

1. Muscles

Skeletal muscles response to distraction is assessed by measuring the muscle enzyme activity namely the aldolase, creatinine phosphokinase and glutamate oxaloacetate transaminase. Muscle fibres demonstrated hypertrophy of organelles with increased myofibrilogenesis in existing fibres. Increased numbers of muscles satellite cells and myoblasts of their fusion into myotubes indicated formation of new muscle tissue itself. The results indicate that lengthening cause temporary damage to muscles. During a 10 percent lengthening, the damage is far less and the recovery is more rapid in multistage than single step lengthening. Ever suggested that 10 percent of lengthening is the limit of safety.

2. Nerves

The effect of distraction in nerve tissue varies with the rate of distraction. Focal swelling and damage of nerve fibres is caused by 1 mm per day distraction in a single step. At 1mm per day in four steps, more normal looking nerve tissue with less local damage is formed.

3. Blood Vessels

Neoangiogenesis occurs with capillaries of the sinusoidal type with wide lumen and discontinuous endothelium and transport capillaries characterized by a narrow lumen and a continuous endothelium. These vessels anastomose with surrounding soft tissue vessels through multiple perforating vessels.

4. Skin

Skin also shows signs of activation mainly in the basal cell layers of the epidermis, which showed considerable increase in the thickness of the layers.

Biomechanics of the Ilizarov External Fixator

The most important factor in the efficiency of biplanar fixator is stability. Stability of a system is the resistance offered by it to shear of deforming forces and this in turn depends on the stiffness of the fixator. Stiffness of clinical interest is shear stiffness and axial stiffness.

Shear stiffness

The ability of a fixator to resist translational shear is represented by its shear stiffness for each directional load. The higher the stiffness, the greater the resistance to shearing forces.

The shear stiffness of the ring fixator is evenly distributed in AP and lateral bending and in torsion, but lower than the uniplanar ones to lateral bending, shear resistance. It is comparable to biplanar ones in torsion and comparable or lower in AP bending. It is lower in lateral bending.

The central configurations have a lower axial stiffness than an offset configuration. Increasing wire tension leads to paradoxically lower torsional shear stiffness.

Axial stiffness

The ability of fixator to resist gap closure is measured as the axial stiffness. A high axial stiffness indicates a strong resistance to axial vector of load present in axial or bending loading.

All the uniplanar and biplanar fixator show very high axial stiffness to axial loading. The Ilizarov fixator has a 75% lower stiffness to axial loading than the uniplanar and biplanar Fixator. The central configuration has a lower axial stiffness than an offset configuration.

Experimental studies have shown that optimal biomedical environment is provided by a fixator which demonstrates high shear stiffness and a low axial stiffness without deforming plastically. The highest shear stiffness was achieved by Ilizarov fixator using olive wires. The lowest axial stiffness without deforming plastically was also demonstrated by the Ilizarov fixator.

Thus the cyclic micro motion and the elimination of translational shear endowed the Ilizarov fixator with the most optional biomedical characteristic for fracture healing.

Biomechanics of the wire

1. Tensioned wires

The K wires, 1.5, or 1.8 mm in diameter are made of stainless steel type austenite class ASIS 320. With a mechanical resistance of 120 kg per square millimeter obtained by drawing with cold reduction of the section by about 40 percent and with a metallurgic made up of austenitic crystals elongated in the direction of drawing.

K wires, tensioned across the rings through the bone achieve rigidity equal to half pins of about 3mm deflection while retaining an external fixator's stability. Stability of a system is the resistance offered by it to shear or deforming forces and this in turn depends on the stiffness of the fixator.

Tensioning of wires can be done either with manual tensioners or calibrated wire tensioning device called dynamometer. The amount of tension is decided by the patient weight. In general about 90Kg tension for half rings and 130kg tension for full rings has been advised. Increasing wire tension increases stability by increasing wire stiffness but it also decreases axial micromotion on loading.

In limb lengthening greater tension is generated in the wires due to increasing soft tissue tension from distraction. This may increase wire tension by as much as 50kg.

Increasing the wire tension from 90-130kg increases the bending and axial stiffness but lowers the torsional stiffness.

Multiplanar positioning of the wire on each side of the rings or introduction of further apart with the posts or additional rings increases the stability of the assembly. If the length between the two rings of the component is more, it is preferable to minimize unsupported length by introduction of drop wires or use of more connections or empty rings without wires.

2. The number of wires

A minimum of two wires and preferably three wires must be transfixed to each ring. The more the number of wires the more is the stability of the fixator.

3. Wire spread

When the fixator is stable, one normally sees parallel longitudinally, oriented bone trabeculae forming directly a thin fibrous interzone between the regenerating bone ends.

When the fixator is unstable, the longitudinal trabeculae become wavy and oblique in their orientation and the interzone becomes thickened with fibrous tissue which may lead to a pseudarthrosis. The highest shear stiffness was achieved by Ilizarov 90/90 degrees of off-central 130kg tension by using Olive wire.

4. Off centering

Off centering the bone was associated with a higher axial stiffness and lower torsional stiffness than the centered configuration.

5. Self stiffening effects of wires

Wire achieves increasing rigidity with increasing deflection because the tension of the wires increases when deflected.

6. Olive wires

Olive wires increases stability of the whole assembly and lead to increase in bending, torsion and axial stiffness. Olive wires significantly increases the bending shear stiffness but not the torsional shear stiffness.

Counter opposed olive wires greatly increased the stability of fixation for oblique fractures.

7. Wire diameter

The increase in wire diameter increases the wire tension and decrease in ring diameter increases the stability of the apparatus of axial loads. For children and in thin bones 1.5 mm wire is used. In adults and in large bones 1.8 mm wires are used.

Biomechanics of rings

The rings are fabricated of stainless steel type martensite class ASIS 410. With a mechanical resistance greater than 90kg per square millimeter and a metallurgic make up of superfine ferric carbides. The material which results is magnetic.

The number, size and position of the rings influence the stability of the assembly. Reduction of two centimeters in ring radius results in a 77 percent rise in axial stiffness. An increase in the ring radius reduces axial stiffness by 32 percent and the bending stiffness by 15 percent. Only torsional stiffness increased with ring size.

As the diameter of the ring increases, the wire span must also increase and this lowers stability. Ilizarov recommend 2cm distance between the ring and the skin to allow for swelling of the soft tissue and pin site care and the smallest rig possible should be selected. There should be at least two levels of fixation on each component.

Intrinsic factors determining the stability

1. Mechanical configuration and interlock between bone ends.
2. Area of contact between bone ends.
3. Tension of soft tissues surrounding the bone.
4. Length of the gap between bone ends.
5. Modulus of elasticity of tissue between bone ends.

1. Mechanical configuration and interlock between bone ends

Stability is easy to achieve if the bone fragments fit into each other or engage with compression. Surgical shaping of bones is important. One bone may be inserted into the other or have a good surface for compression. These are five main shapes of bone ends.

a. Rhomboidal – in which stability and bone contact should be enhanced by the use of side to side compression.
b. Marginal which is managed by resecting thin part of bone or transporting an osteotomised fragment into the defect.
c. Trapezoidal – This is managed by resecting into appropriate shape to get stability and compression.
d. Pencil like – which is managed by making one end transverse and directing the other end into the medullary cavity.
e. Cylindrical – which itself is stable.

2. Area of contact between bone ends

The larger the area of contact between the two fragments of bone, the better the bone healing. The bone ends must be shaped to achieve maximum contact.

3. Tension of soft tissue surrounding the bone

Large amounts of fibrous tissue are usually seen between the fragments in non-union. Surgical removal of this scar tissue may be needed as it can displace the fragments and prevent apposition during compression and bone transport.

4. Length of the gap

The larger the gap between bone ends more will be the obstacles on the way.

5. Modules of elasticity of tissue between bone ends

Rigid and stiff tissue between the bone ends prevents movements of the fragments.

Biomechanics of the Fulcrum

K wires can be used as fulcrum. Correction of deformity without a fulcrum requires much more energy and the system is much less efficient. Appropriate placement of fulcrum is essential to prevent slipping and to control the correction of deformity. Fulcrum for frontal plane deformity is usually olive wires and for sagittal plane deformity they are smooth wires though olive wires may also be used. The closer the fulcrum is to the apex of the deformity, the more efficient it will be. In general, the fulcrum wire should be 2-3 finger breadths away from the apex.

Surgical Techniques in the application of Ilizarov Method

Application of the Ilizarov technique to the treatment of non-union depends on the type of non-union hypertrophic or atrophic, extent of infection and condition of soft tissues.

The main surgical principle in the management of diaphyseal bone infection is through debridement of all nonviable tissue. Such debridement often results in a large bone and soft tissue defect creating a formidable situation to overcome with standard grafting and stabilization techniques.

The application of principle of distraction osteogenesis allows bone to be regenerated between bone ends and to stretch it any direction and length to accomplish lengthening, gap reconstruction and correction of deformity in any plane.

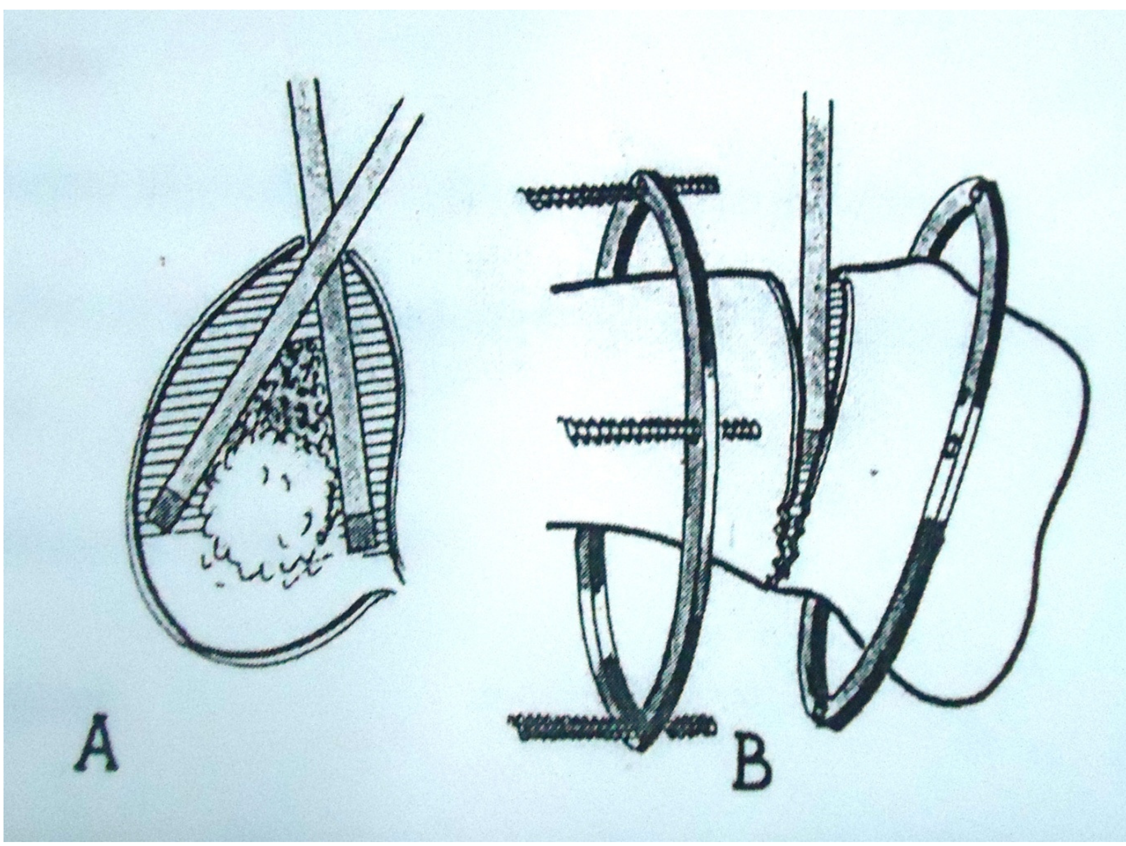
The Ilizarov technique allows radical, circumferential debridement more than possible by conventional techniques, this is possible due to the unique technique of bone transport involving gradual transport of an intercalary segment of bone through the limb while simultaneously lengthening the corticotomy gap and closing the skeletal defect.

The technique of corticotomy

A corticotomy is best described as an open, low energy, subperiosteal partial osteotomy of the cortex followed by manual osteoclasis of the reminder cortical circumference.

A properly performed corticotomy followed by distraction osteogensis serves as a potent biological stimulus for the healing of non union with an increased blood supply to the limb of 330%. The low energy nature of the procedure ensures that the bone osteogenic elements, periosteum, endosteum and marrow are preserved. The undamaged periosteal sleeve serves to minimize fragment displacement and guides new bone formation.

Corticotomy



In the current method, the medial and lateral cortices of the bone are divided subperiosteally by a narrow osteotome through a small, longitudinal skin incision. The far cortex is then divided by one of the two methods.

1. Rotation of the osteotome through 90°
2. Manual rotational osteoclasis

The above technique of corticotomy was found to cause the least damage to soft tissue and medullary blood vessels.

The corticotomy may also be done using a Gigli saw or by multiple drill holes and transverse osteotomy.

Types of corticotomy

a. Transverse / oblique corticotomy-most common
b. Longitudinal corticotomy – used to widen the bone.
c. Splinter corticotomy – used to bridge non-union defects, eliminate partial defects and fill osteomyelitic cavities.

The best regenerate is produced in the metaphyseal area.

Complications

a. Improper technique loading to soft tissue damage.
b. Displacement after corticotomy usually caused by a poorly balanced frame.
c. Incomplete corticotomy.

Latency period

To optimize the conditions of new bone formation, a latency period has been suggested for initial callus formation before distraction, the so called callotasis.

Histologic and biochemical studies conducted on elongated tissue showed that distraction at a rate of 0.5mm/day often led to premature consolidation, while distraction at 2.0mm/day retarded osteogenesis and caused undesirable soft tissue changes.

Elongation at 1mm/day in 4 equal increments led to the most favorable result. (14) (17).

Technique of Bone Transport

Following debridement and creating of a skeletal defect, proximal or distal corticotomy or both is performed to deliver a viable bone fragment that is then transported through the limb into the defect area by slow uninterrupted manipulation of the apparatus. The wires slowly cut through the skin and soft tissues and the bone segment mates with the opposing viable fragment.

Throughout this period, physiological activity as tolerated is encouraged. The intercalary segment is pulled through the limb in one of the several ways.

1. Transport wires are perpendicular to the moving segment and are fixed to the movable ring. At least two wires are needed to stabilize the fragment.

2. Directional wires are inserted obliquely into opposite sides of the bone fragment. They traverse the limb parallel to the bone fragment and exit through the skin beyond the fragment.

   They are not popular as they are technically difficult to place. Also at the time of docking, these wires are too oblique to apply much compression and additional cross wires are required.

3. Intramedullary wires are obliquely inserted to exit the fragment through the narrow canal. They are then inserted into the target fragment medullary canal before they exit the cortex. They are particularly difficult to insert. Ilizarov believes that they damage medullary blood supply. Their advantage is that they can pull the fragment all the way to the target fragments.

Bone transport using wires and rings are also called external technique. It is most useful when the distance is about 5-7 cm.

Bone transport using intramedullary and directional wires is called internal technique. It is useful for bone loss more than 7cm and for a site with deep scars. However, deformity correction and lengthening cannot be performed. (43)

Viability of bone ends

Application of Ilizarov technique depends upon the type of non-union. In the Ilizarov method of treatment, it is more important to classify nonunion.

a. Lax-amplitude of movement greater than 7° in any plane.
b. Stiff-amplitude of mobility no more than 5° - 7° (42)

Treatment of hypertrophic nonunion with minimum amount of infection and no sequestrated bone is monofocal compression. Stabilization stimulates callus formation and union, the infection disappears.

In atrophic non-union with infection bone ends are resected and bifocal or trifocal osteosynthesis is carried out (42) (21).

If the defect does not exceed 2cm, acute shortening is possible. Gyulnazarova and Nadirshnina (1986) studies variations in osteogenesis in lax pseudarthrosis.

a. Pseudarthrosis with pronounced osteopenia of bone ends. This requires minimal resection and compression for 2 weeks followed by distraction.
b. Pseudarthrosis with sclerotic bone ends. The osteogenic reparative process even under the influence of tension stress was impaired. Freshening of bone ends and opening of medullary canal is indicated.

Shape of bone

Appropriate shaping of bone ends is done to increase the area of contact and increase stability. Improved contact is achieved by closed method by approximately placed wires or by open methods in which one fragment is fitted into the other.

Management of defects

Defect-diastasis and shortening

The diastasis is the bone defect as seen in the roentgenogram. Hence restoration of limb length must take into account, the sum of limb shortening as measured clinically and the diastasis as seen in the X-ray (21).

Ilizarov defined the real bone defect as the radiological distance between two bone fragments plus the amount of shortening of the corresponding extremity segment; Calculations are made preoperatively, regarding treatment options. Acute compression of non-union with bone loss more than 2 cm is not advisable because approximation may be followed by folding of soft tissue leading to tropic changes and delayed union.

In stiff hypertrophic non-union, closed monofocal distraction osteosynthesis is used. When there is a diastasis with mobile ends, combined compression-distraction osteosynthesis is used. The diastasis is compressed while simultaneous distraction of corticotomy of one of the fragments was done.

When the diastasis between bone ends is more than 1cm, then the method of consecutive distraction-compression osteosynthesis is used. First one of the fragments is lengthened at the corticotomy site. When contact at the site of non-union is achieved, compression and stabilization of non-union was carried out.

In case of subtotal tibial defects the fibula may be osteotomised proximally and distally and transported medially or spilt longitudinally and distracted towards the tibia to eliminate the defect (42), (21) ,(21),(45).

Fibular Osteotomy

In all cases of lengthening and near the site of compression, the fibula should be either osteotomised obliquely or a segment resected.

Presence of External or Internal Fixation Devices

All infected implants that do not contribute to stability must be removed. If an infected intramedullary nail is present wires must be passed through the cortices avoiding the infected canal and the implant may be removed.

Skin / soft tissue defects

Skin quality and presence of scars influence decision making to a large extent. Distraction of tough scar tissue in the concavity of the deformity may lead the necrosis. Tough and deep scars may serve as an obstacle to bone transport.

Presence of infection

Sequestra and dead bone are removed and infected bone ends must be resected up to healthy bone margins. Corticotomy and the regenerative process initiated by distraction are surprisingly beneficial probably due to increased vascularity.

Presence of Deformity

Compression forces are effective only if axial alignment is restored. Hence angular deformities must be corrected before compression can be applied. In stiff non-union, gradual correction with hinges is advised.

Antibiotics

The enhanced vascularity of the limb induced by distraction is effective in controlling the infection without the prolonged use of antibiotics.

A study by James Aronson (1994) used quantitative technetium scintigraphy to measure regional blood flow in the distraction. At the distraction site flow increased to nearly ten times normal and peaked at 2 weeks. It is then decreased to four to five times the control for the remainder of distraction period. During consolidation, blood flow was to three times normal. These findings confirm that distraction osteogenesis eradicates infection by inducing a prolonged hyper vascular stage. “The infection burned in the flames of the regenerate”. (18).

Bone grafting

Ilizarov does not recommend bone grafting although it often serves as an important adjunct to treatment especially to stimulate bony union at docking sites.

Cattaneo and Catagni (1992) in their series of 28 infected tibial nonunion found no need for autogenous grafting.

Stuart Green (1994) in his series found that of 17 patients treated by bone transport for segmental defects, failure of union at the docking site was present in 7 patients who required supplementary bone grafting. He suggested that the graft be inserted at the time of initial debridement or as the intercalary fragment nears the docking site. In the case of large distance, he recommends insertion at 2cm from the docking site. (44)

The ability to circumferentially resect infected nonviable cortical bone significantly alters antibiotic requirements.

Radiological Assessment of the Regenerate

Catagni has classified different radiographic morphologies related healing time and weight bearing capacity.

Normotrophic regeneration

This is characterized by early radio dense new bone formation occurring approximately 20 days after initial operation. At this time radiograph demonstrate mild osteopenia of the cut ends of each segment. Definite columns of longitudinally oriented new bone appear towards a central corticotomy surface towards a central transverse radiolucent area measuring approximately 4mm in height. Later columns of new bone elongate while maintaining central radiolucent band. Later new bone formation bridges centrally and procedures to a more homogeneous appearance.

Hypertrophic regenerate

This appears radiographically before the twentieth day. The cross sectional diameter of the regenerate exceeds that of the corticotomy site, premature consolidation is possible if the rate of 1mm per day is maintained. This is seen in younger patients, active patients, and good local blood supply within circumferential muscle beds particularly in humerus.

Hypotrophic regenerate

This is by definition delayed in its radiographic appearance. If radiodense new bone does not appear by day 30, or if the bone columns themselves contain multiple breaks, or if has an hour glass shape, then local bone information is inhibited and is considered hypotrophic.

Problems associated with hypotrophic regenerate include prior surgery in the location of the corticotomy with known vascular deficits, local scaring or swelling, lack or function and weight bearing. A slower rate of distraction is instituted till normal regenerate appears.

Ultrasound evaluation of regenerate

Usually bone is poorly seen with ultrasound because the dense cortex does not allow penetration of ultrasound waves. The regenerate on the other hand does not possess cortex and therefore tends itself to examination by this means.

This provides total lengthened distance as well as quality & volume of regenerate bone (7). The technique should probably be considered an adjunct to regular radiographic assessment.

Removal of the apparatus

When the patient is able to walk without pain and X-rays reveal good new bone formation, the nuts of the threaded rods are loosened slightly and the patient is allowed to walk and bear weight for 2 weeks. Look for any abnormal mobility in AP and lateral. If after this period the patient has no discomfort with weight bearing the apparatus may be removed. Optionally plaster of Paris cast may be given for a short period of time after removal of the apparatus.

Problems, Obstacles and complications of bone transport

During the transport, daily physiological changes occur in bone and soft tissue and many predictable difficulties may arise during the distraction and consolidation periods. In most instances appropriate intervention both clinical and surgical lead to resolution of the difficulty prior to apparatus removal. In such instances the difficulty is classified as a ‘problem’ or an ‘obstacle’.

A ‘problem’ is defined as a potential or expected difficulty that arises during the distraction or consolidation phase that is fully resolved by the end of the treatment period by non-operative means.

An ‘obstacle’ is defined as a potential or expected difficulty which arises during the distraction or consolidation period that is fully resolved by the end of treatment period by operative means.

True ‘complication’ includes any local or systemic difficulty that occur during distraction or consolidation that remain unresolved at the end of treatment period and includes any post treatment difficulty.

True complications may be major, minor and permanent. Major complications require operative intervention while minor complications can be resolved non-operatively. Permanent complications cannot be resolved and often preclude the original goals of treatment.

Bony problems

1. Poor quality of the regenerate can be improved by reducing the rate of distraction and then compression followed by distraction called accordion manoeuvre.
2. Malalignment of the transport fragment.
3. Maldocking due to axial deviations.
4. Transport may be obstructed usually by scar tissue between the bone ends usually requiring excisions. Delayed healing at the non-union site usually due to atrophic or sclerotic bone ends, poor contact configuration leading to diminished stability or persistence of infection.

Soft tissue problems

1. Pin tract infection: The most common complication ranges from inflammation to chronic pin track osteomyelitis requiring curettage. This is usually seen when there is reduced pin tension leading to increased in-skin-bone movement.

Dror paley has classified pin track problems into

Grade I – soft tissue inflammation
Grade II – soft tissue infection
Grade III – bone infection

Grade I are treated by local antiseptic and ensuring proper wire tension
Grade II are treated by local injection of antibiotic or oral antibiotics for 1 week.
Grade III are treated by removal of wires, antibiotic and local measures.

2. Joint contractures – may be prevented by regular physiotherapy, splinting and encouraging physiological use of limb.
3. Soft tissue indentation over the gap obstructing bone. Wires may be inserted under the scar and the scar is gradually elevated.
4. Pain is a common complaint in ring fixator application. It can be reduced by attention to detail while applying wires, maintaining wire tension and fixator stability.
5. Neurovascular injuries can be avoided if anatomic guidelines are followed.
6. Patient compliance – This is perhaps the most critical factor determining the success of treatment. The patient must be counseled previously and they must accept that as a treatment modality, bone transport has a long treatment time, multiple complications and may require additional surgical procedures. Physiological use of the limb throughout the time on the fixator is the central pre-requisite to a successful treatment outcome (45), (20).

MATERIALS AND METHODS

This study was conducted 21 cases of infected nonunion of tibia during the period from May 2010 to December2012 in the Department of OrthopaedicsThanjavur Medical College and Hospital, The patient's age range from 23 to 60 yrs. There were 19 male and two female patients.

All cases were result of open injuries. Out of 21 cases, 2 cases were due to accidental fall from height and others were due to vehicular accidents. The latency period before applying Ilizarov fixator range from 3 to 24 months.

According to Gustilo and Anderson grading 11 cases were grade III, 8 cases were grade II and 2 cases were grade I. 17 cases had been treated by debridement and external fixator, 2 cases by long leg plaster and 2 cases by internal fixation.

Type of fracture according to Gustilo and Anderson grading:

Type of Fracture	**Number**	**Percentage**
Open grade I	2	
Open grade II	8	
Open grade III	11	

Management before application of Ilizarov technique

Method	Number	Percentage
Internal Fixation	2	
External Fixation	17	
Long leg plaster	2	

The cases of infected non-union were identified using clinical criteria namely mobility at fracture-site, duration, presence of non-healing wound, radiological evidence of failed bony-union and microbiological evidence of polymicrobial multi-resistant flora, on doing culture of the discharging pus. The cases were assessed pre-operatively, clinically, radiologically, and microbiologically.

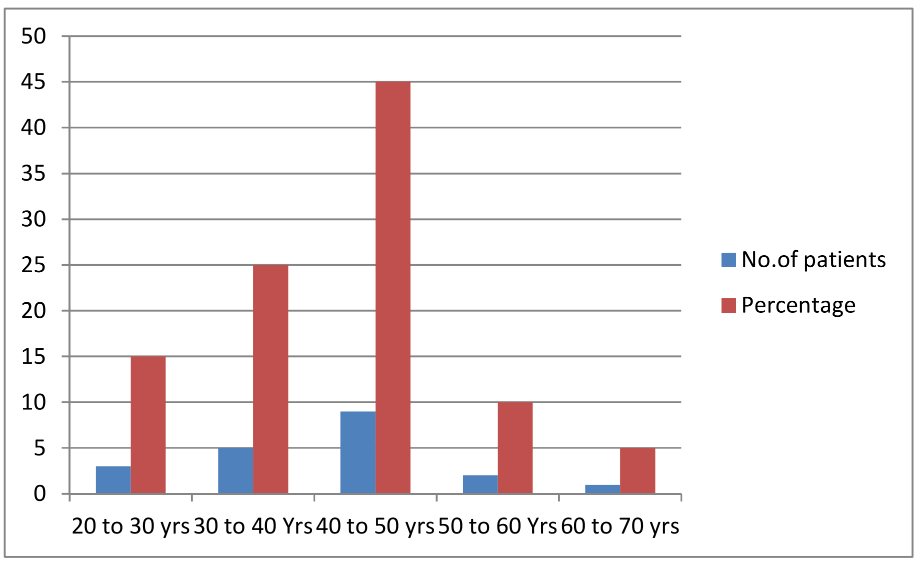
Clinically the mobility at the fracture site, signs of infection and soft tissue condition, limb-length discrepancy and adjacent joints were accessed.

Radiologically the status of bone-ends, the gap and amount of deformity and signs of infection were noted.

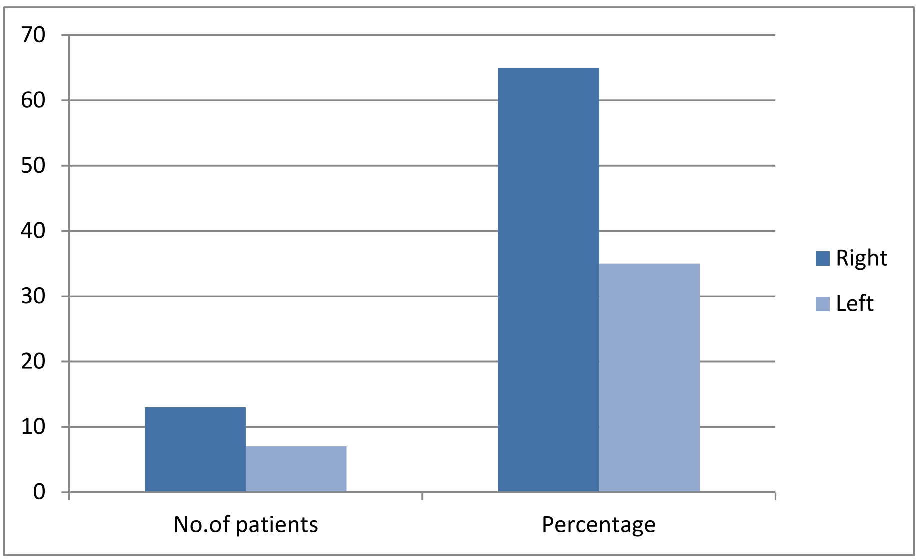
Skin and the sinuses were thoroughly cleaned with antiseptic and a sterile swab is used to get specimen for culture and sensitivity from the non-healing wound.

Non-union was classified based on the Ilizarov system of classification for deciding treatment.

Age	No.of patients	Percentage
20 to 30 yrs	3	15
30 to 40 Yrs	5	25
40 to 50 yrs	9	45
50 to 60 Yrs	2	10
60 to 70 yrs	1	5

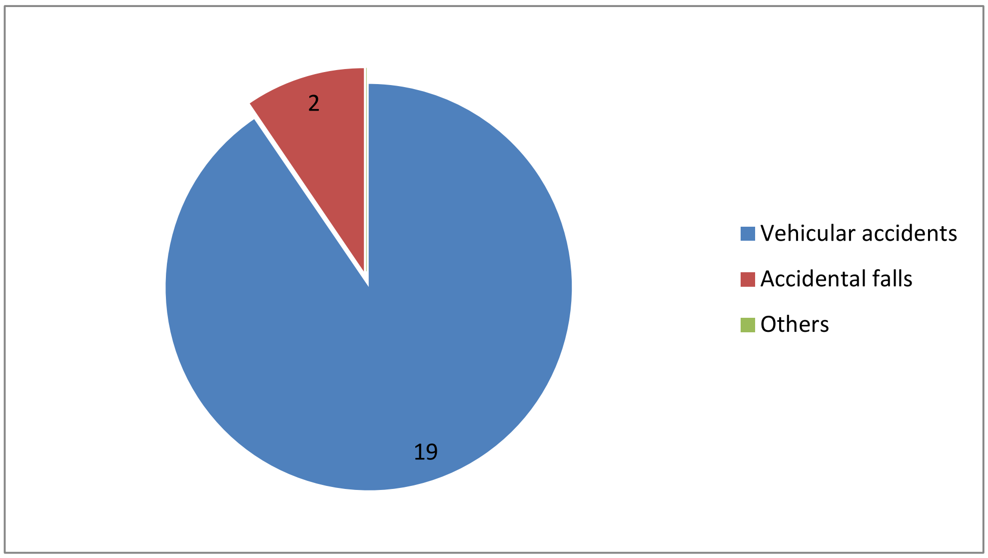


Side	No.of patients	Percentage
Right	13	65
Left	7	35

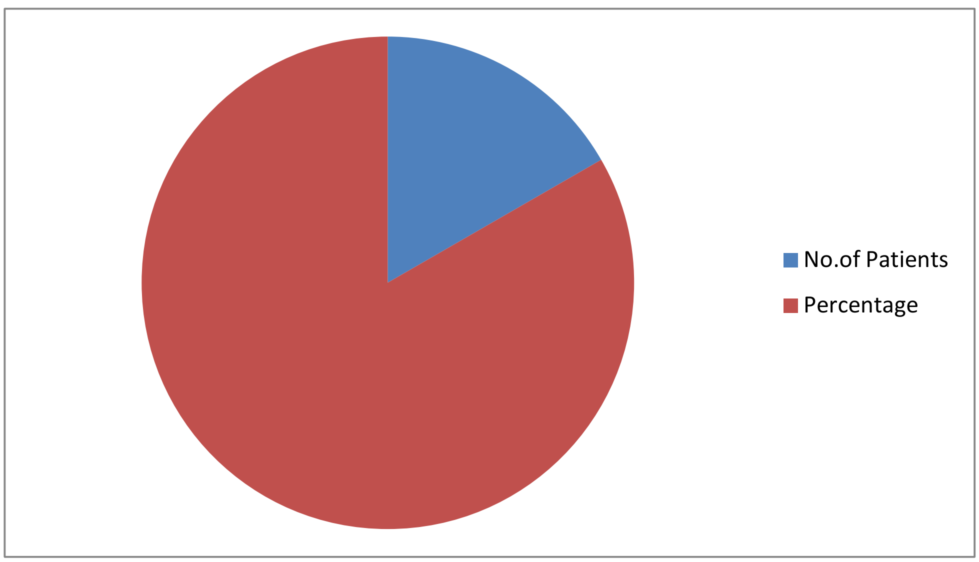


Co-morbid conditions	No.of patients
Diabetes Mellitus	4
Hypertension	1
Others	1

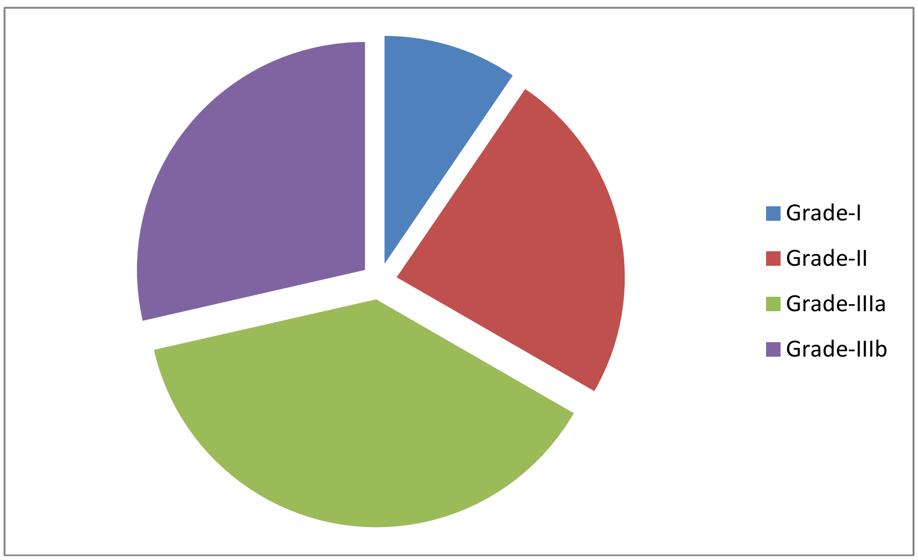
Mode of injury	No.of patients	Percentage
Vehicular accidents	19	90
Accidental falls	2	10
Others	0	0



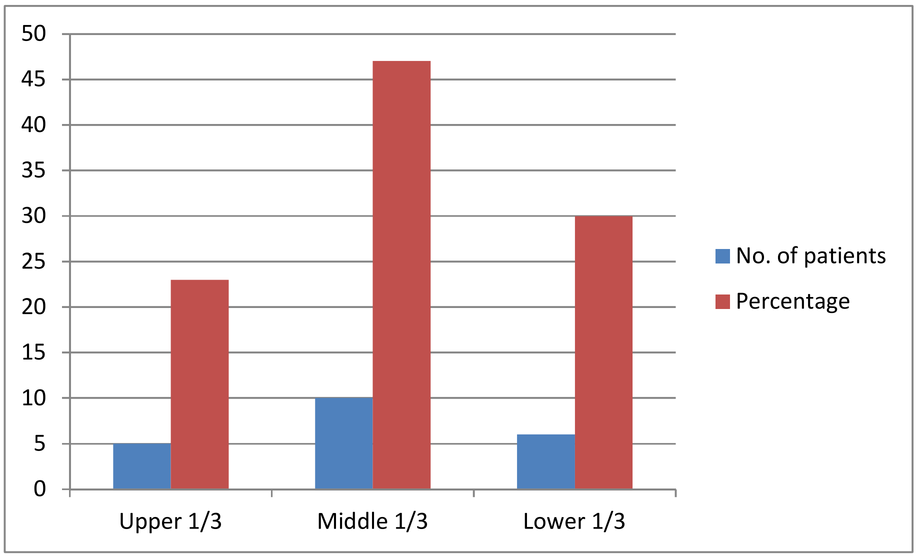
Type of fracture	No.of Patients	Percentage
Closed	2	10
Open	19	90



Modified Gustilo Anderson's classification	No. of patients	Percentage
Grade-I	2	10
Grade-II	5	23
Grade-IIIa	8	38
Grade-IIIb	6	29



Level of fracture	No. of patients	Percentage
Upper 1/3	5	23
Middle 1/3	10	47
Lower 1/3	6	30



Classification

Weber and Cech

Type	Number	Percentage
Hypervascular	17	81%
Avascular	4	19%

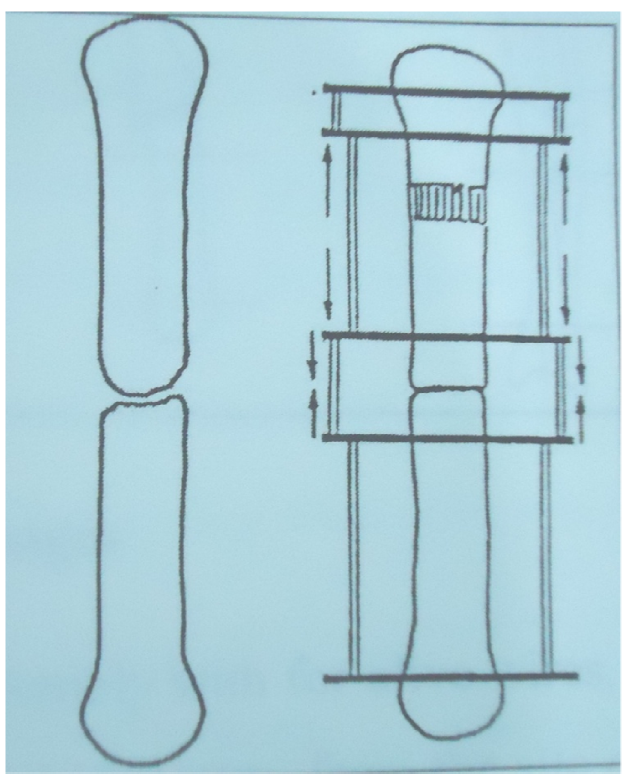
Dror Paley et al (applicable to infected non-union)

Type	Number	Percentage
Type A (less than 1 cm bone loss)	4	19%
A1 (lax)	2	10%
A2 – 1 (Stiff, no deformity)	1	4.5%
A2-s (fixed deformity)	1	4.5%
Type B (More than 1 cm bone loss)	17	81%
B 1 (Bony defect, no shortening)	3	14%
B2 (Shortening, no defect)	3	14%
B3 (Bony defect and shortening)	8	53%
Total	21	

A. Aseptic Non-union without Bone defect.

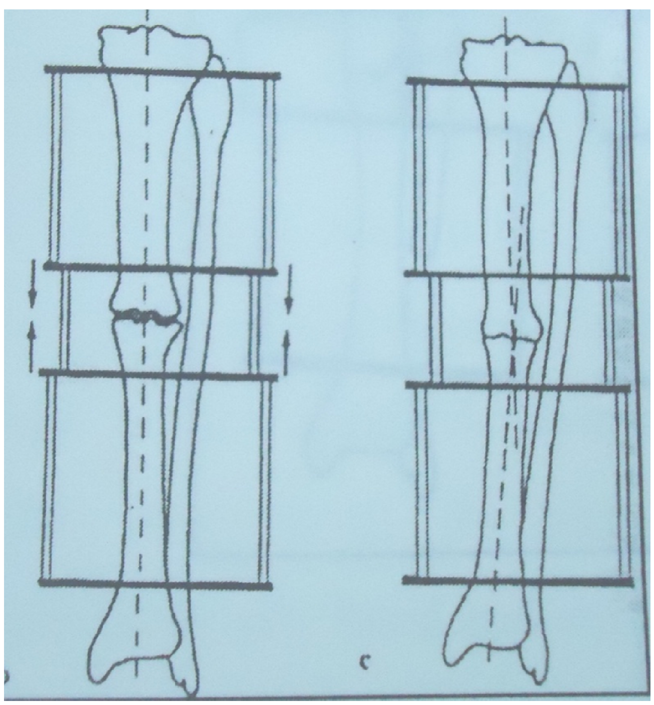
Type A1: Mobile non-union.

The recommended treatment in mobile non union is bifocal osteosynthesis. A corticotomy with gradual distraction and simultaneous compression of the non - union in its proper axis is performed with the proper frame.



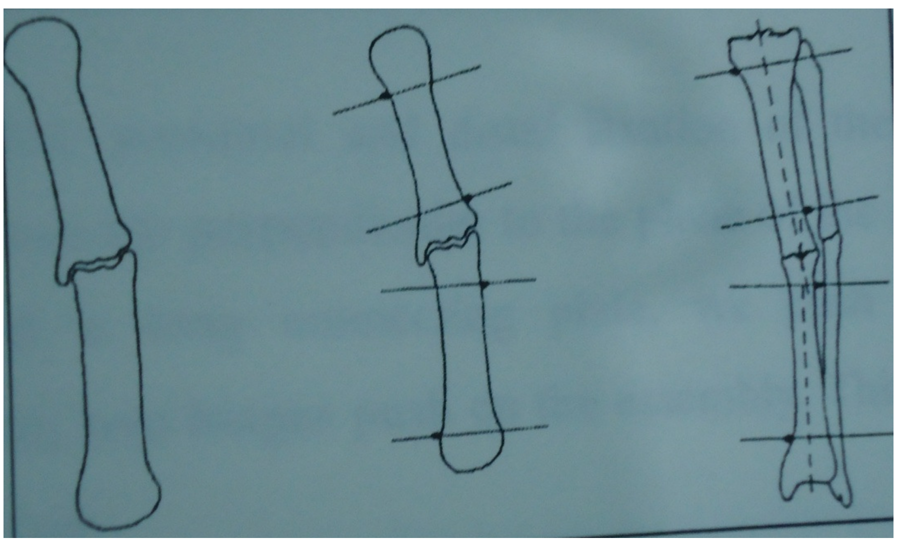
Type A2: Stiff non-Union without deformity

The treatment is monofocal osteosynthesis by gradual distraction followed by compression. For pseudarthrosis, Ilizarov recommends ten to twenty days compression followed by distraction and then finally compression to bridge the non-union.[Accordion technique]



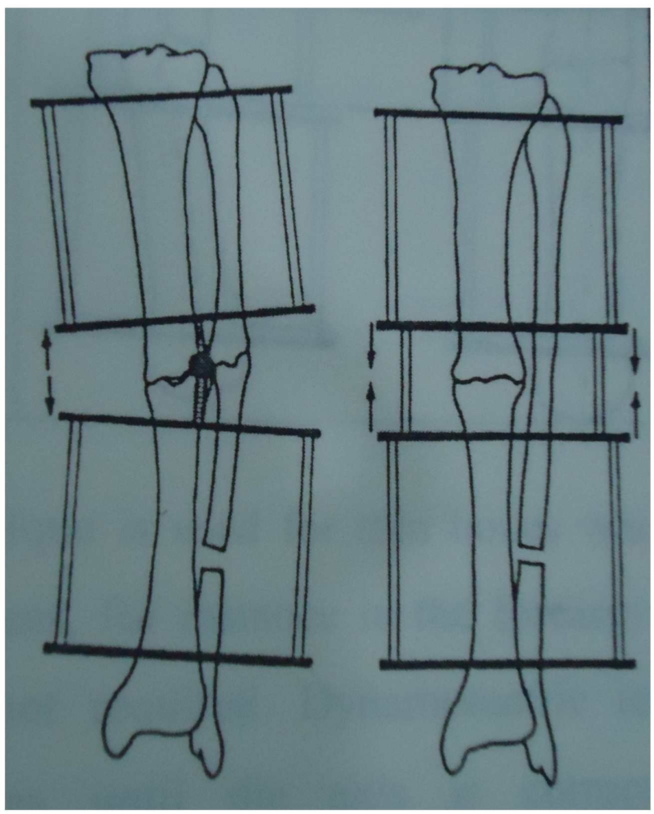
Type A3: Stiff with deformity

The treatment is monofocal osteosynthesis in distraction and compression with simultaneous correction of deformity. In refractory cases, bifocal treatment by addition of a corticotomy may be used.



a. Correction with hinges

A four-ring assembly with for olive wires, two close to the non-union on the convex side, and two away from the site on the concave side is used. Resection of fibula may be needed.



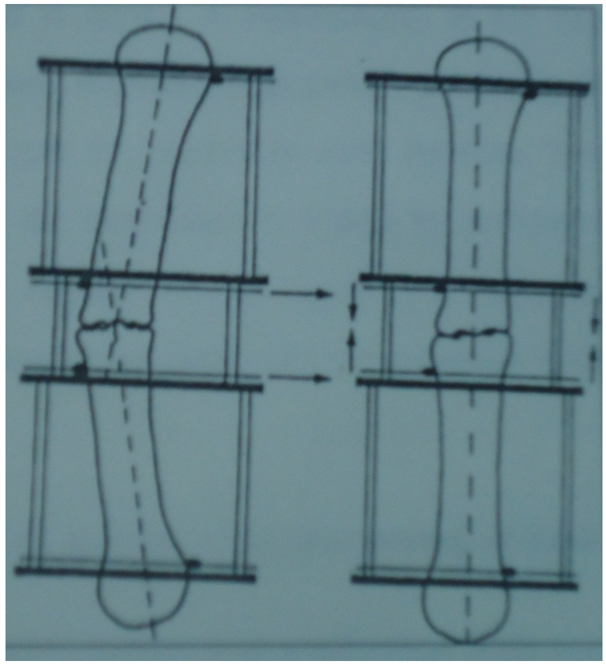
After progressive correction has been carried out either in distraction or in neutral or in compression, depending on the position of the hinges, it is possible to further increase stability by progressive compression equal to ¼ mm twice weekly until bone callus occurs at the site of non-union.

b. Correction with transverse wires

After proximal and distal fixation of the segment, two wires are inserted exactly perpendicular to the plane of the deformity. Using two half rings and a long connecting plate, we push progressively direct this movement, two hinges push on the assembly. This is preferred in correction of the femur.

Correction with olive wires alone

This technique is used for thin bones where the deformity does not exceed 5 to 8 degrees, for instance in the forearm where forceful loading of the segment is not required. Dynamometric tensioners are used on the intermediate wires until the axis is corrected during surgery. The intermediate wires are fixed and compression is carried out during the days that follow at ¼ mm twice weekly.



B. Aseptic Non-union with bone defect

Bone defects were defined as losses of length or intercalary substance exceeding four centimeters. Their main problems to tackle are

1. Non-union
2. Discrepancy in length
3. Atrophy of the segments

A bifocal method must be used to regain the length of the bone and to increase vascularisation of the segments.

Type B1 Length of the limb preserved with bone gap

For loss of substances upto 5 cm, proximal and distal fixation with bone transportation is done. A corticotomy at the upper metaphyseal area created a mobile bone segment with good vascularity that can be transported linearly along the gap by transverse wire fixation. Distraction osteogenesis fills the gap while the non-union is united by compression on bone contact. Transportation is carried out at 1 mm per day, and the non-union is compressed at ¼ mm every three days to maintain stability until the callus is visible.

Type B2 Segment is contact with shortening of limb

A bifocal osteosynthesis is performed with compression of the non-union and lengthening by means of corticotomy if the shortening is less than 5cm. The fibula should also be osteotomised to allow distraction at the corticotomy. If shortening is more than 5 cm then bifocal osteosynthesis is necessary to accelerate healing time.

Type B3 Shortening with defect

The treatment is bifocal osteosynthesis. The distraction is continued till the limb length discrepancy is corrected and compression continued at a rate of ¼ mm in three times a day till union is evident.

C. Infected non-union

Eradication of infection is easier if all infected bone is resected. **"Osteomyelitis burns in the fire of regenerate."** Ilizarov advocated a corticotomy and distraction to increase the vascularity of the limb to eliminate infection. A radical debridement to resect all non-viable infected bone can be done as the Ilizarov technique enables regeneration of bone to fill a defect of almost any size.

In hypertrophic non-union with minimum infection and no sequestra monofocal osteosynthesis alone may be needed. Stabilization stimulated callus formation and union. Once the fracture unites, infection spontaneously disappears. In infected non-union with deformity, monofocal compression is used and the deformity is simultaneously corrected.

In atrophic non-union with infection, the bone ends are resected, medullary cavity is opened and bifocal osteosynthesis is carried out when the resected gap does not exceed 2cm, acute docking can be carried out and . Healing of skin is rapid because of the improved skin vascularity.

The Ilizarov apparatus can be divided into primary and secondary components.

PRIMARY COMPONENTS

These are the standard parts that join the skeleton to the frame.

1. **Transosseous wires –** These are of three types.

a. Wire with trocar point:

Trocar point tips are used for cancellous bone as they will permit better directional control when drilling across cancellous bone in the metaphyseal or epiphyseal segments.

b. Wire with bayonet point:

These are used for cortical bone as they permit drilling across thick diaphyseal cortex without overheating. The tip is equal diameter to the shaft to maximize tight fit within the bone.

c. Olive wires:

These are used for attaining interfragmentary compression, increased stability of the construct by placing in opposite directions on opposite sides of the bone.

2. Rings

Full rings or half rings which can be joined to form full rings are available. Half rings allow more versatility, but full rings have more holes for wires and rods. The size of the ring is chosen based on the maximum diameter of the limb. There should be at least two finger breadth distance between the internal diameter of the ring and the soft tissue.

3. Wire fixation bolts

Two types are available-cannulated type and slotted type. Cannulated types have a longitudinal hole to fix the wire to the ring. The slotted type have an eccentric slot under the bolt head parallel to the long axis and is used to fix the wire crossing the hole eccentrically.

Wires are tensioned by various methods to achieve stiffness. The traditional method involves winding the wire around the neck of the bolt by rotating the nut and the bolt as unit by turning the two wrenches simultaneously. Simple wire tensioners and dynamometric wire tensioners are also available.

SECONDARY COMPONENTS

These are special elements used in the construction of the frame of the apparatus.

1. Threaded rods

These are an integral component in the application of controlled mechanical forces. The rods are used to construct the frame by fixing the adjacent two rings. The pitch of the threads causes 1 mm translation along its longitudinal axis with each one complete turn of the nut. By turning the nuts that fix the rod to the frame, one is able to produce the desired compression or the distraction force in the needed direction. Telescopic rods are also available for distraction.

2. Support posts

These are solid bars with holes with a rounded end. The male post has a threaded rod and the female type has a threaded hole at its base. The support posts are used to fix an additional wire called a drop wire to provided greater stability.

3. Hinges

These are specialized posts with a single hole offset to interface each other with a bolt.

Two types of hinges are available, male and female types. They are used for correction of angulation deformities, mobilization of joints or to prevent subluxation during lengthening. The base of the hinge can also be allowed to rotate forming a universal joint.

4. Connecting plate

These plates are 2 cm broad and 5 mm thick and available in variable length and contain holes along their length at an interval of 5 mm. These are used as extension to the rings when they are not concentric. They are also used in construction of extension frame for fixation of the foot. Twisted plates are also available.

Other parts of a frame include nuts, bolts, washers and bushings.

OPERATIVE PROCEDURE:

All patients in the inclusion criteria were taken up for study. All were assessed pre-operatively. The patients were explained about the procedure and consent was obtained pre operatively. Pre assembled ring was shown to all the patients well before surgery. They were explained about the additional procedure if needed.

1. Wire selection

1.8 mm wires are used for adults and 1.5 mm wires are used for children and in small bones. Trocar printed one is used for metaphyseal bone and bayonet points for diaphyseal bone

2. Wire insertion

Correct placement of wires is essential to control the movement of bone during the various procedures. The following guide lines are to be followed during wire insertion. In our hospital we use Manmann power drill

3. Site of wire fixation

The knowledge of cross – sectional anatomy of the limb is used to pass the wires through safe corridors so that neurovascular structures are not injured. The wires should be inserted from the more vulnerable side and drilling should be started only after reaching the bone.

4. Stop-start technique

Drilling is periodically stopped to prevent over heating of bone as it may cause bone necrosis and loosening of pin and infection.

5. Wire placement

The wire should be placed at right angles to each other for maximum stability. The wires of each pair should be in parallel planes about 0.5 mm apart so that each one should be on either side of each rings.

6. Wire tensioning

The ends of the wire were tensioned with dynamometer tensioner, Pitkar in all cases.

7. Muscle positioning

Muscles should be properly positioned to allow maximum excursion of the adjacent joints. Before piercing, each muscle should be stretched to its maximum at the adjacent joints. Synovium and tendons should not be penetrated.

8. Positioning of skin

Before wire insertion, the skin should be shifted in such a direction as to allow adjacent joint motion. At areas of distraction maximum skin should be left loose. Thus when inserting supracondylar wires before lengthening a femur thorough a distal coricotomy, pull the skin and subcutaneous tissue proximally during wire insertion while at the same time flexing and extending the knee. Similarly shift the skin distally when mounting a ring proximal to the osteotomy.

After insertion of wire, check for evidence of tissue tension while the limb is in its most functional position. If there is tension in the skin the wire is withdrawn below the skin surface and the skin is adjusted to avoid tension and then the wire is advanced so that it passes through the skin in a better position.

If any vessel is injured while inserting wire as evident by a burst in blood or local soft tissue change drilling is stopped and local pressure applied. Distal pulse should be ensured. A new entry is made and drilling done.

Corticotomy

The classic corticotomy was used in the study. The site of the corticotomy was usually upper tribal metaphyseal area, where blood flow is high. Collateral circulation is good and cross sections area is more and the marrow is very cellular.

Technique

After application of the fixator, a 15-10 mm long longitudinal incision is made over the anterior aspect of the tibia just below the tibial tubercle and the periosteum is elevated medially and laterally. A 5mm osteotome is inserted longitudinally into the incision till it reaches bone. Tap the osteotome and twist is to 90 degrees. This spreads the periosteum and avoids transaction. The osteotome is oriented to cut the medial cortex. The lateral cortex of the tibia is cut and the threaded rods between the rings removed. The posterior cortex is fractured y twisting the osteotome and by rotating the distal segment of the leg externally so as to avoid traction on the peroneal nerve at the neck of the fibula. The frame is then reconnected as before.

Latency

Latency is the time period between corticotomy and initiation of distraction. It depends on the site of corticotomy, vascularity, age of the patient quality of the corticotomy and the initial gap after coricotomy. The average latency used during this study is from day 10.

Distraction

The quality and quantity of the regenerate depends on the rate and frequency of distraction. A distraction of 1 mm per day in four increments was used during this study. For angular distraction also one millimeter per day is the recommended rate; for delayed mineralization, the rate may be slowed to 0.75 mm per day or 0.5 mm per day. For soft tissue correction, a rate of 1 mm per day is used.

Post operative management

The patients were advised weight bearing with the use of crutches on day 1. Distraction was taught to the patient and his relatives and they were treated on an outpatient basis with fortnightly reviews. Clearing of the rings and the wires using betadine and hydrogen peroxide was done by the patient. Any problems or obstacles that arose during treatment were managed accordingly.

Frame removal

The healing time is short with the Ilizarov techniques as it is a biological method of healing. In the X-ray, the regenerate should be remodeled with cortex and medullary canal of almost equal cross-sectional diameter to the host bone corticotomy surfaces prior to frame removal.

Dynamisation – The nuts of the frame are loosened and the patient is allowed to walk in the frame. If the patient complaints of no pain, then he is allowed to ambulate in the dynamised frame for about 15 days. Then the frame is removed and a plaster of Paris cast is applied for about a month.

RESULTS:

Final Result grading

GRADING: A.S.A.M.I grading.

The results are divided into bone results and functional results.

Bone results:

1. Union
2. Infection
3. Deformity
4. Leg length discrepancy.

Excellent – union, no infection

Deformity < 7 degrees

Leg length discrepancy <2.5 cm

Good – union plus any two or other criteria

Fair – union plus any one of the other criteria

Poor – non-union or refracture or union with none of the other criteria.

Functional results

Based on 5 criteria

1. Significant limp
2. Equinus rigidity of ankle
3. Soft tissue dystrophy (skin hyper sensitivity / insensitivity of sole or decubitus).
4. Pain
5. Inactivity.

Excellent – Active individual with none of the other four criteria.

Good – An Active individual with one or two of the other four criteria.

Fair – Active individual with three or four of the other four criteria.

Poor – Active individual poor result regardless or other criteria.

The average duration of treatment for infected non – union of tibia is 8.8 months.

Union was achieved in all except two patients. In 2 cases ring was removed due to poor compliance. One among them is a female patient with known Hbs Ag positive patient with segmental fracture. She had bilateral leg fracture. Her left leg was treated with interlocking nail for fracture both bones. She had grade III segmental fracture in right leg. Initially treated with external fixator and later converted into rings. The procedure was explained to her in detail before the ring was applied. She lost the follow up.

The other case of failure occurred in a case of infected non-union resulting from a type IIIB compound fracture. He was previously treated with external fixator and split skin grafting. A four-ring assembly for bifocal osteosynthesis was applied. Patient demanded removal of apparatus. However with the ring in situ, infection had settled down and postero-lateral bone grafting done .Hence frame was removed and long leg cast applied. Patient lost follow –up after that.

One case which did not show any new bone formation even after 9 months of the ring application, underwent bone grafting in fixator in situ and union achieved later.

One case with 6 cm shortening, malunited with shortening of 3 cm due to premature consolidation at the corticotomy site.

One case which implant with segmental fracture had had union in the lower fracture. Upper fracture did not unite. This fracture was dynamised and treatment with bone marrow injection and union achieved.

One patient developed doppler proven pseudo aneurysm from posterior tibial artery and it manifested only 2 weeks after the fixator removal after union had achieved .The vessels ends indentified and ligated.

In one patient there was bone cut through by one of the k wires in the distal ring. It was removed and replaced by another wire and the ends were tensioned properly.

Infected nonunion was treated by debridement of infected bone and necrotic tissue and bifocal osteosynthesis and antibiotics. All of the 21 patients with successful outcome had eradication of infection at about half way of the treatment.

In the final analysis, 2 patients had significant functional impairment and all patients were able to use the limb well at the time of review. The true angle and plane of deformity was calculated from the true anteroposterior and lateral views as described by Dror paley.

Duration of follow up of the patients ranged from 3 months to1 year. At the last follow-up no patient with successful outcome except those two required any orthotic aids. All successful cases returned to full fledged daily activities and most are leading economically productive life. Two patients had length discrepancy more than 1 cm which was acceptable to the patient.

Complications

1. Pain tract infection

All patients developed pin-tract infections at some time during the treatment. Ten patients developed Grade II pin-tract infection which was successfully treated by oral antibiotics and local antibiotic injections. At the time of last follow-up there were no cases of ring sequestrum.

2. Premature consolidation

One of the patient developed premature consolidation at corticotomy site. Her fracture malunited with 3 cm shortening.

3. Delayed consolidation

Delayed consolidation occurred in two cases where there was difficulty in achieving docking. Bone grafting was done. Rings removed once union achieved and followed up with plaster of paris for 1 month period.

4. Neuro-vascular complications

One patient developed common peroneal nerve palsy which did not improved with time.

5. Joint stiffness

At the time of commencement of treatment, 12 patients had equinus deformity of the ankle and stiffness of the knee due to immobilization in cast or in external fixator. Those patients with ankle equinus were asked for procedure with foot assembly. Only 2 patients accepted for foot assembly and correction achieved. At final follow up there was 5 patients had residual equinus contracture.

6. Refracture

None of the patient developed refracture.

Status after follow up

Modality	Yes/No	No.	Percentage
Union	Yes	19	90%
	No	2	10%
Infection	Yes	2	10%
	No	19	90%
Limb – Length discrepancy	Yes	3	14%
	No	16	76%
Radiological union	Yes	18	85%
	No	3	15%
Residual bone deformity	Yes	4	19%
	No	17	81%

Final Result Grading

BONE RESULT

Grade	**Number**	**Percentage**
Excellent	12	57%
Good	5	23%
Fair	2	9%
Poor	2	11%

FUNCTIONAL RESULT

Grade	**Number**	**Percentage**
Excellent	10	47%
Good	6	28%
Fair	4	19%
Poor	1	6%

Thus the final result grading is based on a total of 9 parameters which includes clinical, radiological and functional assessment of the patient some of which are subjective and depends on patient assessment

DISCUSSION

The series includes the study of 21 patients treated for infected non-union using the Ilizarov ring fixator during the period from May 2010 to Dec2012 in the Department of Orthopaedics Thanjavur Medical College and Hospital.

In this study vehicular accidents accounted for 90% of injuries while 10% were due to domestic accidents and falls. Most of the injuries had resulted in considerable tissues injury and bone loss making the injury to be classified as non union before the mandatory six-month period as defined by FDA.

Superficial pin-track infection occurred in all cases. They were treated by parenteral and local antibiotic preparations. In those cases where persistent pin-track infection were present get cured once the apparatus was removed.

Pain during treatment was almost universal in occurrence. It was seen more at sites of a pin-track infection and at the distraction site. Pain interfered with ambulation in some patients. Pain was controlled with the use of various groups of NSAIDS differing from patient to patient. Once the pain was relieved, almost all patients were made to ambulate.

During the study it was noted that pain tolerance and psychological profile of this patient was very important for the implementation of ambulation and physiotherapy. Two patients were engaged in light occupations, while on treatment.

The two failed cases of our series actually were due to poor compliance resulting in premature decision to remove the apparatus before it has served the purpose. Thus the patient selection criteria become one of the most important decisive factors in instituting this form of treatment.

The multiple scars were cosmetically acceptable to all patients. After follow-up it was noted that ankle movements never returned to normal. This was probably due to soft tissue contracture following prolonged immobilization prior to treatment and poor compliance with weight bearing and physiotherapy.

The soft tissue healing was notably accelerated by increased vascularity in the limb. Soft tissue defects which were left opened quickly granulated and skin cover was obtained without skin grafting in 17 cases. Draining sinuses healed spontaneously on the application of the apparatus and restoration of stability. The stability by a properly applied Ilizarov frame is excellent and aids union.

Nonunion presents a therapeutic challenge to the orthopaedic surgeon. When traditional methods of managing these nonunion fail, our study shows that Ilizarov technique provides excellent results for majority of patients.

The following outcomes and observations were drawn up from the study:

1. The Ilizarov technique allows early function of the limb resulting in adequate stimulus for soft tissue and bone healing.
2. Proper selection of patients by avoiding extremes of age, and assessing compliance by the patients is essential for the successful application of the Ilizarov technique.
3. Proper placement of K wires and rings is essential for maintaining adequate rigid fixation.
4. Fast healing of soft tissues associated with distraction osteogenesis reduces the need for plastic surgery of obtaining skin coverage.
5. Bone grafting is supplemented in attaining union when the Ilizarov technique is used in special situations where the ends of bones were too narrow to be docked. We had found bone grafting to be useful.
6. Dror Paley's classification is applied only after radical debridement of an infected fracture.
7. Infection can be eradicated due to radical debridement of infected fracture, surrounding soft tissue and by increasing the vascularity of the limb.
8. Pin tract infection, soft tissue contractures and refracture can be prevented by adequate supervision and proper post ring protected weight bearing for 6 month with polypropylene tibial braces.

9. Duration of treatment is relatively short when considering the complexity of the problems.

10. A trial of loosening of the ring for one month before removal of the apparatus and external splintage for one or two month after removal of the fixator is very important to prevent refracture.

11. Physiotherapy and functional use of the limb from the first week after application of the fixator is essential for successful treatment of the non-union.

12. The Ilizarov technique is the treatment of choice for infected non-union of long bones.

Proper understanding of the biological and biomechanical principles of the Ilizarov method and their careful application give excellent results in almost all cases of infected non-union.

CONCLUSION:

The permutations and combinations of the Ilizarov ring fixator made it versatile and almost a salvage procedure as it addressing all the problems of open or infected musculo-skeletal injuries and achieving union in 90 percent cases in this series. However it has a slow learning curve. The few complications which occurred in our earlier cases did not recur later. The main way to avoid mistakes and complications in ring external fixation is to follow the advice from the master Prof G.A.Ilizarov.

"A surgeon should know not only the device but also the method proposed with it, therefore its detailed mastering is a must''.

S.NO:	NAME	AGE	SEX	REGION AND INJURY	PRIMARY TREATMENT	CORTICOTOMY	DURATION OF TREATMENT	COMPLICATIONS	ADDITIONAL PROCEDURES	RESULTS
1.	KM	64	M	Mid 1/3	Debridement and external fixator	No	7 months	Pin tract infection	None	Union achieved
2.	PA	35	F	Lower 1/3	Debridement and external fixator	yes	9 months	Premature consolidation at corticotomy site	Bone grafting at the docking site.	Malunion with 3 cm shortening.
3.	MI	43	M	Upper 1/3	Debridement and external fixator	No	8 months	Pin tract infection	None	Union achieved
4.	KP	57	M	Middle 1/3	Debridement and external fixator	No	12 months	Pin tract infection	Bone grafting	Delayed union with bone grafting
5.	MG	48	M	Upper 1/3	Debridement and external fixator	Yes	8 months	Pin tract infection	None	Union with 2cm shortening
6.	RJ	23	M	Middle 1/3	Debridement and external fixator	Yes	5 months	Pin tract infection	None	Union achieved
7.	JP	25	M	Upper 1/3	Plaster of paris	No	8 months	Pin tract infection	None	Union achieved
8.	GY	31	F	Segmental fracture	Debridement and external fixator	Yes		Pin tract infection. Persistent infection.	Addition of wires in the 2nd ring with posts.	Lost follow up. Poor compliance.
9.	RC	42	M	Middle 1/3	Debridement and external fixator	No	7 months	Pin tract infection	None	Union achieved
10.	MH	35	M	Upper 1/3	Debridement and external fixator	yes	11 months	Pin tract infection	None	Union achieved
11.	SL	28	M	Lower 1/3	Plaster of paris	No	6 months	Common peroneal nerve palsy	None	Union achieved
12.	MV	35	M	Lower 1/3	Debridement and external fixator	yes	18 months	Poor compliance	Bone grafting and frame removal	Lost follow up
13.	KY	54	M	Upper 1/3	Internal fixation	No	12 months	Persistent infection	None	Bone marrow injection.

S.NO:	NAME	AGE	SEX	REGION AND INJURY	PRIMARY TREATMENT	CORTICOTOMY	DURATION OF TREATMENT	COMPLICATIONS	ADDITIONAL PROCEDURES	RESULTS
14.	PB	28	M	Segmental	Interlocking nail	No	9 months	Delayed union at upper fracture site	Bone marrow injection	Union achieved with varus angulation.
15.	SV	30	M	Lower 1/3	Debridement and external fixator	No	12 months	Pin tract infection	None	Union achieved
16.	GN	45	M	Lower 1/3	Debridement and external fixator	No	10 months	Pin tract infection	None	Union achieved
17.	VM	50	M	Lower 1/3	Debridement and external fixator	No	11 months	Pin tract infection	None	Union achieved
18.	PV	43	M	Middle 1/3	Debridement and external fixator	No	10 months	Pin tract infection	None	Union achieved
19.	GP	33	M	Upper 1/3	Debridement and external fixator	No	6 months	Delayed union at upper fracture site	Bone grafting	Union achieved
20.	SK	34	M	Upper 1/3	Debridement and external fixator	Yes	9 months	Pin tract infection.3 cm shortening.	Bone grafting	Union achieved with 2 cm shortening.
21.	RV	29	M	Middle 1/3	Debridement and external fixator	No	6 months	Pseudoaneurysm from PTA 2 weeks after ring removal	Aneurysm explored and ends ligated.	Union achieved.

PTA: Posterior tibial artery.

APPENDICES

a)Master chart

b)Proforma

c)Bibliography

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CASE I

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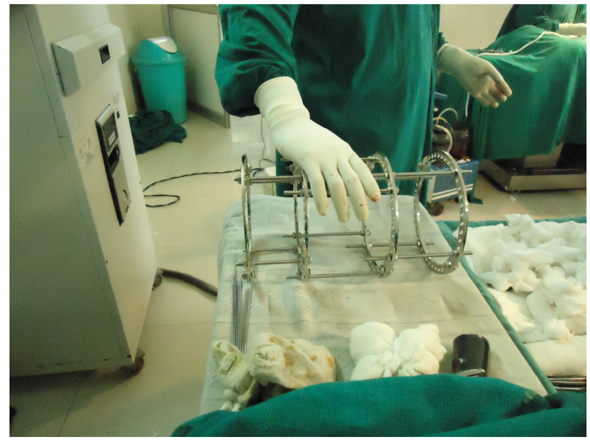
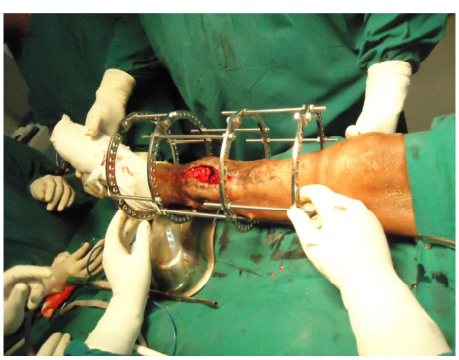
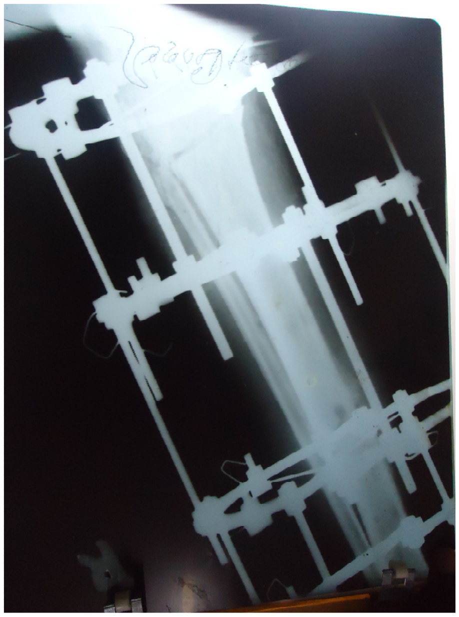


PRE ASSEMBLED RING

SURGICAL PROCEDURE



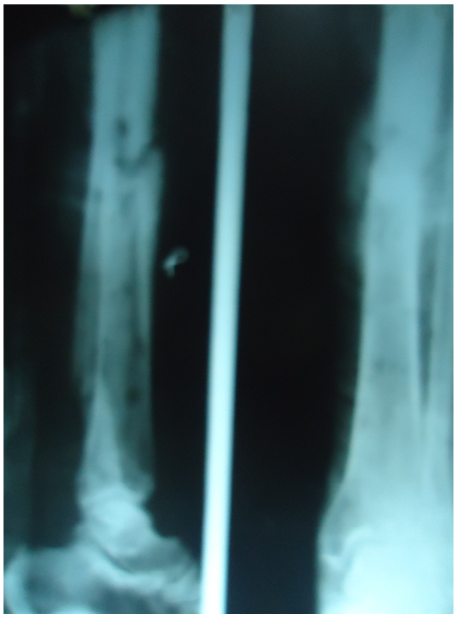


CORTICOTOMY

UNION

POST RING REMOVAL PICTURE

CASE II



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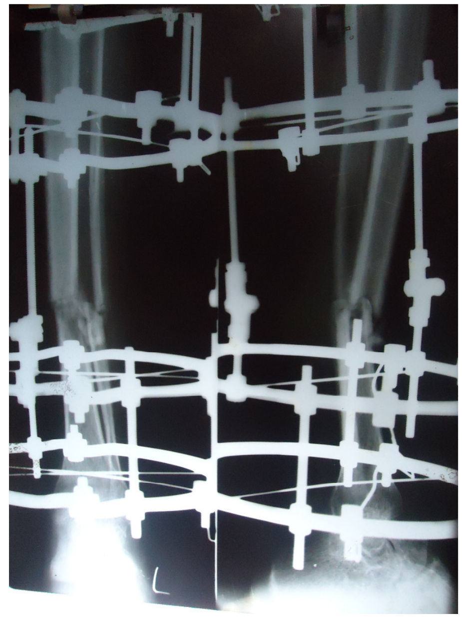

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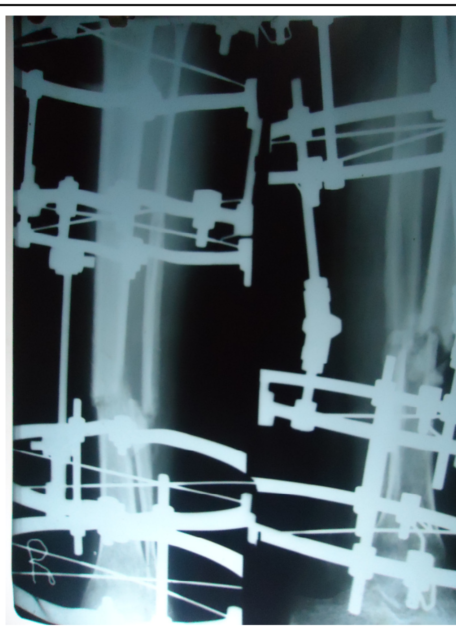

UNION

POST OPERATIVE XRAY AFTER RING REMOVAL


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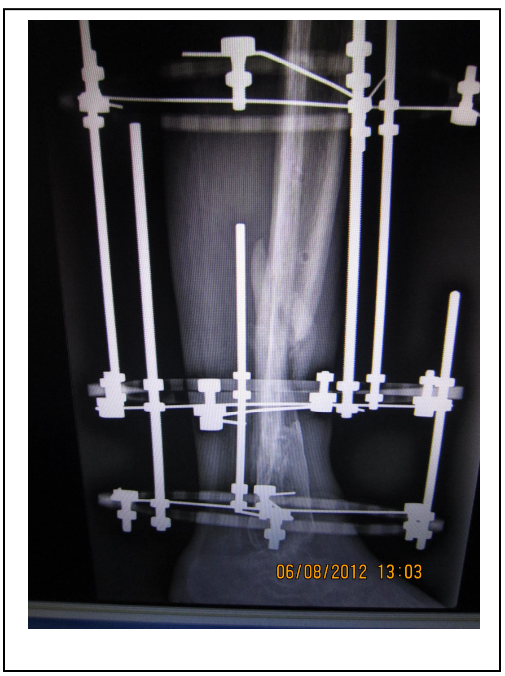
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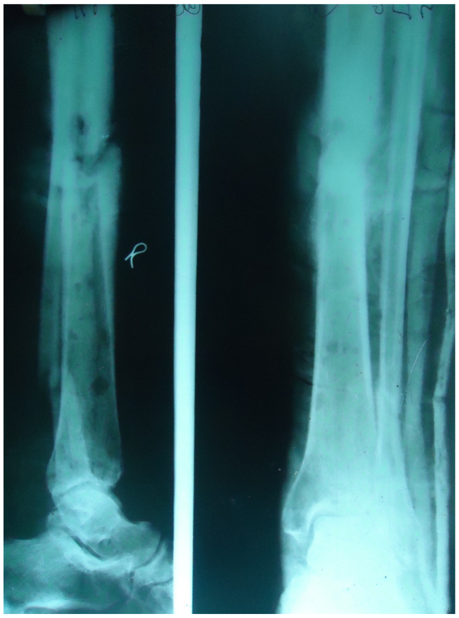

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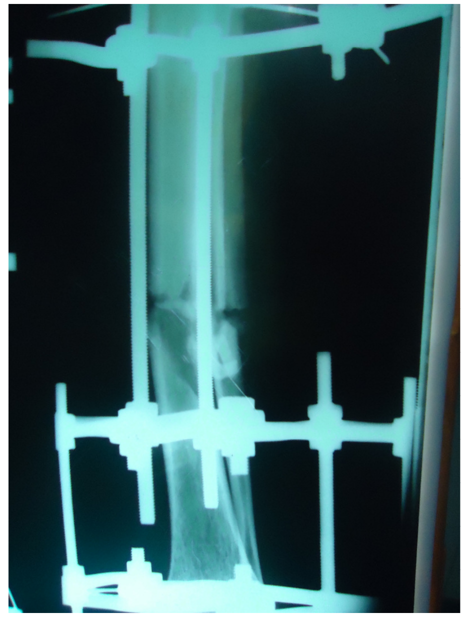

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